SUMMER EVAPORATION INTENSITY AS A DETERMINING FACTOR IN THE DISTRIBUTION OF VEGETATION IN CONNECTICUT

GEORGE ELWOOD NICHOLS

For an area of its size, the state of Connecticut exhibits considerable diversity both in topography and in vegetation. From a geographical standpoint three well defined regions may be recognized: the Western Highland, the Eastern Highland, and the Central Lowland. The surface of the Highlands is for the most part exceedingly rugged, and in the northern part of the state, especially in the Western Highland, elevations of 300 or more meters are common. The Central Lowland is characterized, on the whole, by its gentler contours and lesser elevations. Over large areas here the surface is almost level, while the hills, as a rule, seldom reach a height of more than 75 meters. Exception to this latter statement, however, must be made in the case of the trap ridges which traverse the Lowland from north to south, dividing it lengthwise into two sections. In topography these conform with the Highlands rather than the Lowland. Geologically, as well as topographically, the Highlands contrast sharply with the Lowland. Except for limited areas of limestone, the Highlands are underlain by granites, gneisses, and schists. The Lowland rocks are sandstones and shales. Throughout the state, however, the underlying rock is in large part covered over by a mantle of glacial drift which in places is more than 50 meters in thickness.

The vegetational differences between various parts of Connecticut are not so sharply or clearly defined. Moreover, the situation is complicated by the fact that practically the entire area at one time or another has been deforested, while a large share of it is at present under cultivation, so that the nature of the original plant covering has become more or less modified. Considering the vegetation of the state in its entirety, the ultimate climatic formation is a forest dominated by various deciduous trees and hemlock. Of the virgin forest scattered remnants are occasionally encountered, but for the most part the present woodlands are second growth.

These undoubtedly differ in many respects from the original forests. Nevertheless, it seems probable, due to the sprouting capacity of the majority of the constituent trees, that in favorable cases, except for a decrease in the proportion of hemlock and a corresponding increase in the proportion of chestnut, the general aspect of the forest has not greatly altered during the last three centuries. The composition of this forest, however, was never uniform throughout the state. In northwestern Connecticut the original forest was of the so-called Northern hardwood type. Here the dominant trees were sugar maple, beech, and hemlock, associated with which were yellow birch, chestnut, and other hardwoods. Just how large a portion of the state was originally clothed by this type of forest is uncertain, but it undoubtedly was present throughout the greater part of the northern half of the Western Highland and extended southward toward the shore of Long Island Sound. In all probability it was also characteristic of at least the northern portion of the trap range and of the northernmost section of the Eastern Highland. Along the coast and throughout the greater extent of the Central Lowland, so far as can be determined, the most widely distributed type of original forest was composed largely of chestnut and various oaks. The trees characteristic of the northern hardwood forest were also present here, but were relatively less abundant and more restricted in their occurrence. In the forests of this area the tulip tree was frequently an important component. The original forests of the Eastern Highland, except in the northernmost part, would appear to have resembled more closely those of the coast and Lowland than those of the Western Highland. In the present forests the prominent trees are the oaks, especially the white and the red oak. Chestnut, while present, is much less conspicuous than in the Lowland forests. Hemlock, beech, and maple are of subsidiary importance.

There are other important and even more striking vegetational dissimilarities between various parts of the state. The discussion of these, however, is reserved for papers in course of preparation, in which the plants of the state are to be considered from an ecological standpoint.[1] It was the primary object of the experiments

[1] The first paper of this series, "The vegetation of Connecticut I. Phytogeographical aspects," has already been published (Torreya **13**: 89–112. 1913).

to be described in the present paper to determine whether the distribution of the climax types of vegetation could in any way be coordinated with differences in the evaporating power of the air during the growing season. As is generally recognized, one of the greatest dangers that beset the growing plant is loss of water through transpiration. In ordinary plants, as soon as the amount lost in this manner exceeds that absorbed by the roots, the plant wilts. The rate at which transpiration goes on in any particular plant is regulated largely by the evaporating power of the surrounding air, and this in turn is dependent upon a complex of factors, such as humidity, temperature, direction and velocity of wind, etc. When exposed to uniform atmospheric conditions, however, it is known that the rate at which water is transpired by different kinds of plants varies, mesophytes transpiring more rapidly, xerophytes more slowly, and so on. That the great centers of plant distribution in various parts of the United States are directly related to well marked differences in the summer evaporation intensity has been ably demonstrated by LIVINGSTON,[2] while the earlier work of TRANSEAU[3] indicated an analogous correspondence between the precipitation-evaporation ratios for the entire year and forest distribution. It seemed possible, therefore, that in the area under consideration similar relations on a smaller scale might be detected.

Accordingly, with this object in view, during the summer of 1912 continuous evaporation records were taken at numerous localities in the state by means of porous clay cup atmometers of the type devised by LIVINGSTON.[4] For assistance in carrying out these experiments the writer is indebted to the various cooperators named below. The expense necessarily involved was in large part defrayed by Yale University. Altogether, 16 more or less widely separated stations were selected, and these were fairly uniformly distributed, through the three geographical regions of the state, 7 being located in the Western Highland, 3 in the Central Lowland, and 6 in the Eastern Highland. Three of the stations, one in each geographical region, were situated near the coast. The writer personally selected the sites and installed the atmometers at all the stations except

[2] Plant World **14**:205–222. 1911.

[3] Amer. Nat. **39**:875–889. 1905.

[4] Carnegie Inst. Publ. no. 50. 1906.

Storrs and Haddam. So far as possible, the sites were made to conform with one another, the instruments being placed in the open, where they would be freely exposed to the action of both sun and wind. Brief comment regarding the nature of the respective sites, together with the names of the various observers, is given in the following paragraph.

WESTERN HIGHLAND.—Salisbury: open hillside, north exposure, altitude 210 m.; Mrs. CHARLES S. PHELPS. North Colebrook: open field, slightly shaded in early morning and late afternoon, altitude 224 m.; station of particular interest on account of proximity to large tract of virgin northern hardwood forest; Mr. CARRINGTON PHELPS. West Cornwall (Cream Hill): hillside, west exposure, slightly protected from wind by trees, altitude 390 m.; Mr. C. L. GOLD. Litchfield: lawn in proximity of buildings, altitude 330 m.; Rev. JOHN HUTCHINS. Hawleyville: hillside lot, west exposure, slightly shaded in early morning and late afternoon, altitude 156 m.; Mr. C. B. HAWLEY. Collinsville: hillside lawn, west exposure, buildings in vicinity, altitude 135 m.; Mr. G. J. CASE. CENTRAL LOWLAND.—Hayden: open field, altitude 15 m.; site typical for neighboring tobacco plantations; Misses HELEN and GRACE CLAPP. Southington: lawn, in proximity of building; altitude 45 m.; Miss EUNICE MACKENZIE. EASTERN HIGHLAND.—Haddam: hill crest, altitude 144 m.; Professor A. L. DEAN. Storrs: open hillside, west exposure, altitude 195 m.; Professor L. A. CLINTON. Colchester: hillside cemetery, slightly shaded in late afternoon, east exposure, altitude 150 m.; Mr. H. P. BUELL. Danielson: hillside, west exposure, altitude 75 m.; Mr. F. E. BITGOOD. Voluntown: hill crest, altitude 82 m.; Mr. J. L. HERBERT. COASTAL REGION.—Niantic: lawn, in proximity of trees and buildings, slightly shaded in early morning, within 90 m. of sea shore, altitude 5 m.; Mrs. F. H. DART. New Haven: open lawn, slightly protected from wind, about 3 km. from shore, altitude 18 m.; G. E. N. Westport: hillside, about 0.5 km. from shore, altitude 30 m.; Mr. GRENVILLE MACKENZIE.

In each of the above mentioned localities a pair of atmometers was installed side by side, about 50 cm. apart. The bottles to which the cups are connected were set upon a T-shaped wooden support, being held in position by zinc casings made for the purpose. The base of the cup itself was thus raised about 56 cm. from the ground, or high enough to insure free circulation of the air about it. The entire apparatus was inclosed within a coarse-meshed chicken-wire cage. Of the two cups installed at the beginning of the season at each station, one was replaced by a fresh one after an interval of 5 weeks; the second original cup was renewed at the end of 10

weeks; and 5 weeks later a fourth cup was substituted for the one which at that time had been longest in operation. Distilled water was used in all cases. The majority of the instruments were set up during the last week of May and continued in operation until September 14. At the end of the season the cups were returned to the writer and restandardized,[5] the readings being then corrected in the usual manner,[6] and all results coordinated with those derived from standard cups. Except where for one reason or another particular cups were manifestly unreliable, the records of the two were averaged to obtain the accepted readings.

In this way a practically complete set of weekly readings throughout the season has been tabulated for nearly every station. Such a series of figures brings out a number of interesting facts. It is found that for the state as a whole the maximum weekly rate of evaporation for the season occurred during the first week in July, when there was an average water loss from each cup of 211 cc. During this week the instruments at Hayden evaporated 256 cc., and at 5 other inland stations in the Lowland and Eastern Highland the rate exceeded 225 cc., while at Niantic there was a loss of but 144 cc. At no time during the season did the amount evaporated during the recorded week at any of the stations in the Western Highland or in the Coastal Region amount to as much as 225 cc. The lowest rate of evaporation throughout the state was observed during the first week in September, when the average was 41 cc., the minimum being reached at Niantic (22 cc.). The mean weekly evaporation rates for the state as a whole, based on the averages of all the stations, were as follows:

June	1–June	8	146 cc.	July	27–Aug.	3	121 cc.
"	8– "	15	178 "	Aug.	3–Aug.	10	113 "
"	15– "	22	124 "	"	10– "	17	108 "
"	22– "	29	153 "	"	17– "	24	53 "
"	29–July	6	211 "	"	24– "	31	125 "
July	6– "	13	155 "	"	31–Sept.	7	41 "
"	13– "	20	119 "	Sept.	7– "	14	104 "
"	20– "	27	170 "				

[5] See Nichols, G. E., A simple revolving table for standardizing porous cup atmometers. Bot. Gaz. **55**: 249–251. 1913.

[6] See Plant World **13**: 111–115. 1910.

There seems to be no obvious advantage, so far as general considerations are concerned, in setting forth in detail the results for each week in each locality. It has rather seemed simpler to give local averages for longer periods, a method already adopted by LIVINGSTON[7] in presenting similar data. The periods selected correspond approximately to the three summer months—June, July, August—and the first half of September. The mean weekly evaporation rates for the various stations during these periods are given in table I.

TABLE I

MEAN WEEKLY EVAPORATION RATES IN CC., AS RECORDED BY THE POROUS CUP ATMOMETER, FOR 16 STATIONS IN CONNECTICUT, FROM JUNE 1 TO SEPTEMBER 14, 1912. FIGURES IN PARENTHESES INDICATE NUMBER OF WEEKS FOR WHICH READINGS ARE RECORDED, IF LESS THAN THE STATED PERIOD

Station	June 1 to June 29	June 29 to Aug. 3	Aug. 3 to Aug. 31	Aug. 31 to Sept. 14	Average for season	June 1 to Aug. 3
Salisbury	152	168	109	69	134	161
Colebrook	133 (2)	119	87	53	100 (14)	122 (7)
Cornwall (Cream Hill)	115	130	79	65	103	123
Litchfield	113	147 (4)				130 (8)
Hawleyville	119	141	113	89	121	131
Collinsville	144	161	98	71	128	154
Hayden	165	182	124	77	148	174
Southington	170	167	109	70	140	168
Haddam	197	184	99	67	149	189
Storrs	182	175	100	97	146	178
Colchester	157	156	99	79	131	157
Danielson	181	173	100	101	143	172
Voluntown	176	165	112	81	143	170
Niantic	104	105	71	40	87	104
New Haven	146	145	102	68	123	146
Westport	142	165	107	71	134	156

In considering the evaporation intensity of the air as a possible factor affecting the distribution of the vegetation in this region, it seems reasonable to assume that its effect on plants is felt most keenly during the earlier part of the growing season, at a time when growth and development are taking place most rapidly and when the immature tissues and organs are as yet inadequately protected from excessive transpiration. An examination of the first four

[7] Plant World **14**:205–222. 1911.

columns of figures in table I reveals the fact that during the first two monthly periods the mean weekly rate of evaporation far exceeded that maintained during the latter part of the season. In other words, the period of maximum evaporation coincided approximately with the more critical period of vegetative activity. In view of this correlation, coupled with the natural assumption that it is the periods of excessive evaporation that are most influential in determining the character of vegetation, it has been thought best in drawing conclusions to disregard entirely the data obtained during the latter part of the season, when for the most part a uniformly low rate of evaporation prevailed throughout the state, and to base deductions on the observations of these first two months. The mean weekly rates of evaporation obtaining at the various stations from June 1 to August 3 have therefore been indicated in the last column of table I. With these figures as a basis, it is a simple matter to compute approximately the relative evaporating power of the air for the various geographical and vegetational regions of the state during the period of combined maximum vegetative activity and evaporation intensity for the year 1912. Upon averaging the results for the inland stations of the Highlands and Lowland and of the stations along the coast, it is found that the weekly water loss, as recorded by the porous cup atmometer, was as follows: Western Highland, 137 cc.; Central Lowland, 171 cc.; Eastern Highland, 173 cc.; Coastal Region, 135 cc. It would thus appear that the area dominated largely by the mesophytic northern hardwood type of forest, and the strip along the coast, constitute areas of relatively low evaporation intensity; and that the rate of evaporation in the Eastern Highland, where oaks predominate in the forest, is somewhat higher than that in the Central Lowland, where the more mesophytic chestnut is the character tree. The relatively low evaporation rate along the coast was not wholly unexpected and will be referred to again. Explanation for the gradual diminution in evaporation intensity apparent in passing from west to east along the coast may be looked for in the fact that while the western part of the shore is shut off from the ocean by Long Island, the eastern portion is more exposed and therefore possesses a more maritime climate.

In the foregoing paragraphs no account whatever has been taken of the varying amounts of precipitation occurring in different sections of the state. But since the amount of water present in the ground and therefore available for plant use is in itself a potent factor in determining the character of vegetation, and since its abundance is so largely controlled by the amount of precipitation, it is necessary, in order to gain a comprehensive view of the situation, that the relationship between the phenomena of precipitation and evaporation within the area under discussion be considered. So far as observed, there is no constant ratio between the rate of precipitation and the intensity of evaporation. Thus the rate of evaporation during a heavy rain is hardly lower than during a dense fog. But the ratio between the *amount* of precipitation and that of evaporation, especially over considerable periods of time, is of vital significance. In the state of Connecticut there is an average annual precipitation of 120.9 cm. (47.59 inches).[8] This is distributed approximately as follows: Western Highland (inland), 126.8 cm. (49.94 in.); Central Lowland (inland), 119.6 cm. (47.08 in.); Eastern Highland (inland), 117.7 cm. (46.35 in.); Coastal Region, 116.8 cm. (45.98 in.). Of more special interest, however, for the purpose of comparison with the observed rates of evaporation, are the amounts of rainfall that occurred in the various localities during the past season for the period extending from June 1 to August 3. These, together with the contemporaneous evaporation records, are therefore indicated in table II. For convenience in comparing the two sets of data, the evaporation readings, heretofore given in terms of cc., are here expressed in units of depth as well, the conversion being made with reference to a more or less arbitrarily chosen free water surface.[9]

An examination of table II shows very convincingly that, for the period under observation, nowhere in the state would the amount of rainfall have compensated for the amount of water which would have been evaporated from a free water surface during

[8] Based on records from 14 scattered stations. This and the following figures regarding precipitation have been computed from statistics published in the *Monthly Weather Review* of various dates.

[9] The standard water surface on which these reductions are based is that used by LIVINGSTON (see Plant World **14**: 214, 215. 1911).

the same interval. As is indicated in the last column, the disparity was least in the Western Highland, greatest in the Eastern Highland. The fact that, despite this at first sight rather startling deficiency in precipitation as compared with evaporation during this particular season, plants were still able to maintain the balance between absorption and transpiration may be attributed partly to the manner in which evaporation is modified by the physical structure of various soils, partly to the adequacy of the groundwater supply, which in turn is largely dependent on the influx of water

TABLE II

MEAN WEEKLY RATES OF RAINFALL AND EVAPORATION DURING THE PERIOD OF 9 WEEKS FROM JUNE 1 TO AUGUST 3, 1912

	Mean weekly rainfall		Mean weekly evaporation			Ratio between rainfall and evaporation
	cm.	in.	cc.	cm.	in.	
Western Highland..	1.19	0.47	137	1.94	0.76	0.61
Central Lowland...	1.14	0.45	171	2.42	0.95	0.47
Eastern Highland ..	1.02	0.40	173	2.45	0.96	0.42
Coastal Region.....	0.91	0.36	135	1.91	0.75	0.48

at times of the year when the effects of evaporation are less pronounced, and partly to various structural peculiarities of the plants themselves by which transpiration is regulated. Nevertheless, the marked excess in the rate of evaporation over that of precipitation at such a critical period in the life of the plant cannot but make some impress on the character of the vegetation. Another interesting fact is brought out in this table. As has already been noted, the absolute amount of evaporation in the Coastal Region is even lower than that in the Western Highland. But taking the ratio between the amount of evaporation and that of rainfall as a criterion, it is seen that conditions in the Coastal Region approximate more closely those in the Central Lowland. Similarly the less mesophytic nature of the Eastern Highland is forcibly accentuated.

It is fully appreciated that too definite conclusions cannot be drawn from such a series of experiments conducted for but a single season. It is recognized, furthermore, that it is well-nigh impossible to select with certainty in different localities representative sites

in which the instruments will be exposed to absolutely parallel atmospheric conditions. The danger in placing too much reliance on a single set of data for a given locality was impressed upon the writer by results secured from a supplementary series of instruments which was operated in various plant habitats in the vicinity of New Haven for the last five weeks of the season. During this period the mean weekly evaporation rate at the central station averaged 86 cc. Instruments in the other sites averaged as follows: exposed summit of trap ridge, about 6 km. from coast, altitude 81 m., 138 cc.; salt marsh, 128 cc.; lee of low sand dunes along shore, about 100 m. removed from salt marsh station, about 131 cc.; open bog, altitude 6 m., 81 cc. More accurate conclusions as to the evaporation intensity prevailing throughout the state might of course be derived from a series of instruments placed in diverse habitats in each of the localities selected and operated for several seasons, but at the present time no further investigation along these lines is contemplated. And while the data obtained from the experiments of this one season do not permit final conclusions, they at least suggest that the evaporation intensity of the air may be a factor of no little import in determining the character of the vegetation in different parts of Connecticut.

YALE UNIVERSITY